A systematic review of the influence of the implant-abutment connection on the clinical outcomes of ceramic and metal implant abutments supporting fixed implant reconstructions

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Abstract: OBJECTIVES The objective of this systematic review was to assess the influence of implant-abutment connection and abutment material on the outcome of implant-supported single crowns (SCs) and fixed dental prostheses (FDPs). METHODS An electronic Medline search complemented by manual searching was conducted to identify randomized controlled clinical trials, prospective and retrospective studies with a mean follow-up time of at least 3 years. Patients had to have been examined clinically at the follow-up visit. Failure and complication rates were analyzed using robust Poisson regression, and comparisons were made with multivariable Poisson regression models. RESULTS The search provided 1511 titles and 177 abstracts. Full-text analysis was performed for 147 articles resulting in 60 studies meeting the inclusion criteria. Meta-analysis of these studies indicated an estimated 5-year survival rate of 97.6% for SCs and 97.0% for FDPs supported by implants with internal implant-abutment connection and 95.7% for SCs and 95.8% for FDPs supported by implants with external connection. The 5-year abutment failure rate ranged from 0.7% to 2.8% for different connections with no differences between the types of connections. The total number of complications was similar between the two connections, yet, at external connections, abutment or occlusal screw loosening was more predominant. Ceramic abutments, both internally and externally connected, demonstrated a significantly higher incidence of abutment fractures compared with metal abutments. CONCLUSION For implant-supported SCs, both metal and ceramic abutments with internal and external connections exhibited high survival rates. Moreover, implant-supported FDPs with metal abutments with internal and external connections for also showed high survival rates.

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A systematic review of the influence of the implant-abutment connection on the clinical outcomes of ceramic and metal implant abutments supporting fixed implant reconstructions.

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Abstract

Objectives:

The objective of this systematic review was to assess the influence of implant abutment connection and abutment material on the outcome of implant-supported single crowns (SCs) and fixed dental prostheses (FDPs).

Methods:

An electronic Medline search complemented by manual searching was conducted to identify randomized controlled clinical trials, prospective and retrospective studies with a mean follow-up time of at least 3 years. Patients had to have been examined clinically at the follow-up visit. Failure and complication rates were analyzed using robust *Poisson* regression and comparisons were made with multivariable *Poisson* regression models.

Results:

The search provided 1511 titles and 177 abstracts. Full-text analysis was performed for 147 articles resulting in 60 studies meeting the inclusion criteria. Meta-analysis of these studies indicated an estimated 5-year survival rate of 97.6% for SCs and 97.0% for FDPs supported by implants with internal implant-abutment connection and 95.7% for SCs and 95.8% for FDPs supported by implants with external connection. The 5-year abutment failure rate ranged from 0.7% to 2.8% for different connections with no differences between the types of connections. The total number of complications was similar between the two connections, yet, at external connections abutment or occlusal screw loosening were more predominant. Ceramic abutments, both

internally end externally connected, demonstrated a significantly higher incidence of abutment fractures compared with metal abutments.

Conclusion:

For implant-supported SCs, both metal and ceramic abutments with internal and external connections exhibited high survival rate as well as metal abutments with internal and external connection for implant-supported FDPs.

Introduction

The rehabilitation of missing or lost teeth by means of implant reconstructions is a predictable treatment option. The survival rates of implant-supported single crowns and fixed dental prostheses (FDPs) range between 89% and 94% at 10 years (Jung et al. 2012; Pjetursson et al. 2012). Implant reconstructions are perpetually exposed to forces during function which can influence the survival and incidence of complications. Abutments from different materials, like titanium, gold, alumina and zirconia proved to be biocompatible and allow for a healthy mucosal attachment (Abrahamsson et al. 1998; Vigolo et al. 2006; Nakamura et al. 2010; Linkevicius et al. 2008). Consequently, the clinician can choose the appropriate abutment material in each individual situation. Metal abutments can shine through thin mucosa and compromise the esthetic outcome more often than zirconia abutments (Sailer et al. 2009a). Out of this reason, ceramic abutments, specifically zirconia abutments, became popular and are being frequently used.

Abutments can be connected to the implant in an internal or external way. Findings from in vitro studies showed improved stability for internally connected abutments (Sailer et al. 2009b; Truninger et al. 2012). This biomechanical advantage seems clinically beneficial in terms of a lower incidence of abutment screw loosening for internally connected abutments (1.5%) compared to externally connected abutments (7.5%) (Gracis et al. 2012). On the other hand, fractures were reported for internally connected zirconia abutments, especially when being out of one piece (Carrillo de Albornoz et al. 2014; Passos et al. 2016; Ferrari et al. 2016; Fabbri et al. 2017). In contrast, successful survival rates of 100% for externally connected zirconia abutments were observed at 12 years in function (Zembic et al. 2013, 2015). A disadvantage of the externally connected abutments might be the possibility of abutment screw fractures (Zembic et al. 2014).

Although the clinical performance is not differing significantly for abutments with external or internal connections, there is a shift towards internal connections across most implant systems today (Zembic et al. 2014). Internally connected zirconia abutments with a metal base connecting to the implant might be the preferred option in future. This hybrid abutment showed more favorable results with regard to the fracture strength compared to zirconia abutments out of one piece (Butz et al. 2005; Sailer et al. 2009b; Stimmelmayr et al. 2013; Chun et al. 2015; Yilmaz et al. 2015; Alsahhaf et al. 2017; Elsayed et al. 2017). In addition, the esthetic advantage of a ceramic abutment in area of the emergence profile is combined with the biomechanical advantage of a metal abutment. Up to now, there is no clinical data for this abutment type and it is unclear, how the cemented junction will evolve over time. For decision making with regard to the abutment type and material, systematic reviews are a perfect tool to provide the practitioners with recent clinical outcomes on the highest level of evidence (Egger et al. 2001). Taking developments and progress in implant dentistry into account, this information needs to be updated every once in a while. This systematic review is an update of the previously published one on ceramic and metal abutments (Sailer et al. 2009a).

The aim was to estimate and compare the clinical performance and 5-year survival rate of metal and ceramic abutments and the reconstructions supported by these abutments, as well as the incidence of technical, biological and esthetic complications with specific focus on the different implant-abutment connection types, i.e. the external and internal connections.

Materials and Methods

The present review analyzed the influence of the type of implant-abutment connection, i.e. internal and external connections, on the outcomes of the implant abutments and the supported reconstructions. This literature review updated the literature search and data extraction of a previously published systematic review on the performance of ceramic and metal implant abutments supporting fixed implant reconstructions (Sailer I et al. COIR 2009), and included feasible literature published thereafter.

General search strategy

The focused question for this review was determined according to the well-established PICO strategy (Population, Intervention, Comparison, and Outcome) (Sackett 2000, Akobeng 2005).

- Population: Partially edentulous patients
- Intervention: Implant-supported fixed reconstructions based on ceramic/ metal abutments with internal implant-abutment connection
- Comparison: Implant-supported fixed reconstructions based on ceramic/ metal abutments with external implant-abutment connection
- Outcome: Survival and complication rates of the abutments and reconstructions

Focused question

The focused question of the present review was: “In partially edentulous patients with fixed implant-supported reconstructions, do the type of the implant abutment connection and the implant abutment material influence the clinical outcomes?”

Literature search strategy

The literature search for this systematic review focussed on the outcomes of fixed implant reconstructions supported by ceramic or metal implant abutments with internal and/or external implant-abutment connections.

All relevant literature published in the years from 1990 until the end of 2017 was included. The review was prepared in the context of the EAO Consensus Conference 2018.

An extensive search for clinical trials was conducted, through PubMed, from 1990 until and including December 2017. No language limits were applied. An additional manual search was executed to identify relevant articles among the reference lists of all included full text articles and among the references of the several systematic reviews on implant abutments and implant-supported fixed reconstructions.

Search terms

The terms and strategy of the literature research were:

("dental implants"[MeSH Terms] OR ("dental"[All Fields] AND "implants"[All Fields]) OR "dental implants"[All Fields]) AND ("dental abutments"[MeSH Terms] OR ("dental"[All Fields] AND "abutments"[All Fields]) OR "dental abutments"[All Fields]) AND (("2009/01/01"[PDAT]: "2017/12/31"[PDAT]) AND "humans"[MeSH Terms]).

The search was performed rather inclusively, with least possible filters or limitations in order to include as many feasible studies as possible for further exclusion during evaluations on title, abstract or full text levels.

Inclusion criteria

Clinical studies were considered for inclusion if all of the following inclusion criteria were met:

- Human studies with at least 10 patients treated
- A follow-up time of at least 3 years
- Patients treated with:
  - Fixed implant reconstructions;
  - All kinds of implant-types and implant-diameters and implant-abutment connections;
  - Implants in anterior regions; Implants in posterior regions.
- Detailed information on the implant-abutment connection (internal, external)
- Detailed information on the abutment material utilized (ceramic, metal)
- Detailed information on the restoration material utilized (all-ceramic, metal-ceramic)
- Restoration type clearly described (single crowns (SC), multiple-unit fixed dental prostheses (FDPs)), and clinical outcomes from SC and FDP reported separately
- If multiple-publication on the same patient cohort, only the publication with the longest follow-up time was included

- In studies mixing data on different restoration types and/or materials data were only included if less than 10% of the reconstructions were of the second type/ material.

Exclusion criteria

Studies not meeting all inclusion criteria were excluded. Also reports based on questionnaires, interviews, hence studies without clinical examination of the patients, and case reports were excluded from the present review.

Selection of studies

Two authors (CZ and IS) independently screened the titles derived from the initial search in consideration for inclusion. Disagreements were resolved by discussion. After title screening, the abstracts obtained were screened for inclusion by CZ and MS. Whenever an abstract was not available electronically it was extracted from the printed article. Based on the selection of abstracts, articles were then obtained in full text. Again, disagreements were resolved by discussion. Finally, the selection based on inclusion/exclusion criteria was made for the full-text articles by the authors AZ, CZ and MS. For this purpose, materials and methods, results, and discussions of these studies were screened. The selected articles were then double-checked by the senior authors IS and BEP. Any issues regarding the selection that came up during the screening were discussed within the group in order to reach a consensus.

Data extraction and method of analysis

Four reviewers (AZ, MS, CZ and BEP) independently extracted the data of the selected articles using data extraction tables. For standardization purposes, every author extracted the data of the same 3 articles in the beginning of the literature analysis, and the results were then compared within the group and any disagreements were discussed aiming at a consensus to standardize the subsequent analyses.

In some case, when a publication did not provide sufficient information but was judged worthy to be included, the authors were contacted by e-mail or telephone.

All extracted data were double-checked, and any questions that came up during the screening and the data extraction were discussed within the group.

Information on the following parameters was extracted: author(s), year of publication, study design, total number of included patients, number of patients at the end of the study, follow-up time (range, mean), mean age of patients, patient age range, number of abutments/ reconstructions included, number of abutments/ reconstructions in-situ at the end of the observation, dropouts, location– type of jaw (maxilla, mandible), location in the jaws (anterior, posterior), implant type, implant diameter, implant-abutment connection type, reconstruction type, reconstruction fixation method (screw-retained, cemented), published abutment/ reconstruction survival rate, location of lost abutments/ reconstructions, number and type of technical complications (technical, biological), number and type of biologic complications, number and type of esthetic complications, reported number of abutments/ reconstructions free of complications.

Data extraction

From the 60 included studies, information on failures of the supporting implants, the abutments and the reconstructions was extracted. Information on technical, biological and esthetic complications was also retrieved. Technical complications were characterized by mechanical damage or mismatch of implants, abutments and/or the supra-structures. Among these, “fractures of abutments, screws or reconstructions”, “screw or abutment loosening”, “loosening of the reconstruction”, “gap or misfit between implants and abutments or abutments and reconstructions” and “fractures or deformations of the veneering ceramic”. From the included studies, the number of events for all of these categories was abstracted and the corresponding total exposure time of the implants, abutments and reconstructions was calculated.

Biological complications were characterized by biological processes affecting the supporting tissues. “Soft tissue complications”, “soft tissue recessions” and “substantial (>2mm) marginal bone loss” were included in this category.

Quality assessment of the included study

The Newcastle-Ottawa Scale (NOS) was used to evaluate the quality of the included prospective and retrospective studies. Studies with NOS scores of less than 5, 5 to 7, and above 7 were considered as having low, moderate and high methodological quality, respectively. Moreover, a new quality assessment scale for prospective and retrospective observational studies was proposed and implemented *(Geneva-Reykjavik Quality Assessment Scale, GRS).*

The pro- and retrospective observational studies included in the present systematic review report mainly on outcomes that are either present or not, such as loss of an implant, abutment or reconstruction, fracture of components, loosening of abutments and screws. Hence, these studies do not involve detailed measurements that can be accompanied with the risk of measurement bias.

In the new quality assessment scale used in the present systematic review (*GRS*), prospective cohort and case-series, with a low drop-out rate (< 4% per follow-up year), representing a high attrition of the subjects and a low risk of selection bias, were considered to be of a *high methodological quality*. Prospective studies that did not report the drop-out rate or had a drop-out rate higher that 4% per follow-up year, and retrospective case-series that gave detailed description of the entire patient cohort treated and reported low drop-out rate (< 4% per follow-up year) of subjects, were considered to be of *moderate methodological quality,* representing a medium risk of selection bias. Finally, retrospective case-series that did not elaborate on the entire cohort, did not report the drop-out rate or had a drop-out rate higher that 4% per follow-up year, were considered to be of a *low methodological quality* representing a high risk of bias of a selection bias.

Observational studies exhibit generally a risk of inclusion bias exists, i.e. the included subjects may not represent the general population since specific subjects were selected to be included.

Statistical analysis

By definition, failure and complication rates are calculated by dividing the number of events (failures or complications) in the numerator, by the total exposure time (implant, abutment, SCs or FDPs-time) in the denominator.

The numerator could usually be extracted directly from the publication. The total exposure time was calculated by taking the sum of:

1) Exposure time of implants, abutments, SCs and FDPs that could be followed for the whole observation period.

2) Exposure time up to the failure of implants, abutments, SCs or FDPs that were lost due to failure during the observation period.

3) Exposure time up to the end of the observation period for implants, abutments, SCs or FDPs that did not complete the observation period due to reasons such as death, change of address, refusal to participate, non-response, chronic illnesses, missed appointments and work commitments.

For each study, event rates for implants, abutments, SCs or FDPs were calculated by dividing the total number of events by the total implant, abutment, SC or FDP exposure time in years. For further analysis, the total number of events was considered to be Poisson distributed for a given sum of implant exposure years and Poisson regression with a logarithmic link-function and total exposure time per study as an offset variable was used (Kirkwood & Sterne, 2003a).

Robust standard errors were calculated to obtain 95 percent confidence intervals of the summary estimates of the event rates (White 1980 & White 1982).

To assess heterogeneity of the study specific event rates, the Spearman goodness-of-fit statistics and associated p-value were calculated. Five year failure and complication proportions were calculated via the relationship between event rate and survival function S, S(T)= exp(-T *event rate), by assuming constant event rates (Kirkwood & Sterne, 2003b). The 95 percent confidence intervals for the failure and complication proportions were calculated by using the 95 percent confidence limits of the event rates. Multivariable Poisson regression was used to investigate formally whether event rates varied by connection type (internal vs. external), abutment material (metal vs. ceramic), retention type (cemented vs. screw-retained), position in the dental arch (anterior vs. posterior) and study design (prospective vs. retrospective). All analyses were performed using Stata®, version 12.0 (StataCorp LP, College Station, Texas, USA).

Results

Included studies

A total of 60 studies were included in the present systematic review, from which 48 reported exclusively on implant-supported single crowns (SCs), 7 exclusively on implant-supported fixed dental prostheses (FDPs) and the 5 remaining studies reported both on implant-supported SCs and FDPs. The studies reporting on SCs were published between 1996 and 2018, with 2011 as the medium year of publication. For FPDs the publications were on average older than for SCs with 2005 as medium year of publication (Tables 1-4). The included studies evaluated total of 4446 implant abutments supporting SCs with a mean follow-up time of 5.1 years and 1542 implant abutments supporting fixed dental prostheses with a mean follow-up time of 5.6 years. From the studies reporting on the crown material, connection and retention type utilized, 58% were metal-ceramic and 42% were all-ceramic, 59% had internal and 41% external connection, 84% of the SCs were cemented and only 16%were screw-retained. Comparable figures for the included FDPs were 97% metal-ceramic, 3% zirconia-ceramic, 48% internal connection, 52% external connection, 59% cemented and 41% screw-retained. Many of the included studies, however, did not provide this information. The majority of the studies were conducted in an institutional environment, such as university or specialized implant clinics and about one third of the studies were performed in private practice setting.

Methodological quality of the included studies

Utilizing to the Newcastle-Ottawa Scale all the included studies received a score of 5 or 6 representing a moderate methodological quality. According to the new quality assessment scale (*GRS*) also applied in the present systematic review 62% of the studies were judged to have high, 28% moderate and 10% low methodological quality. The latter studies represented a less evident representativeness and higher risk of selection bias than the rest of the evaluated studies (Tables 1-4).

Implant – abutment connection at SCs

Twenty-nine of the included studies reported on implant-supported SCs with internal implant-abutment connection, 24 studies on SCs with external connection, 3 studies reported on both connection types and 2 studies did not specify the connection type utilized (Tables 1&2).

The 5-year failure rates for abutments supporting SCs were 2.3% for internal and 1.3% for external connections, and the respected failure rates for implant-supported SCs were 2.4% and 4.3%, respectively. The differences in failure rates between internal and external connection did not reach statistical significance (p=0.161 & 0.266) (Table 5). The total number of technical complications was also similar for both connection types, with a 5-year complication rate of 10.1% for internal connection and 12.4% for external connection, respectively.

Regarding technical complications, there were significantly more screw loosening reported for implants with external implant-abutment connection.

There was also significantly more ceramic chipping reported for implant-supported SCs retained with internal connection compared with external connection.

For all other technical complications, the difference between internal and external implant-abutment connection did not reach statistical significance (Table 5).

The 5-year rate of the total number of biological complications was 6.7% for the internal connection, compared with 4.3% for the external implant-abutment connection. The difference between the groups did not reach statistical significance (p=0.364). The incidence of soft tissue recessions tended to be more frequent for internal implant-abutment connection, without reaching statistical significance between different connection types (p=0.060) (Table 5).

<u>Implant – abutment connection at FDPs</u>

Five of the included studies reported exclusively on implant-supported FDPs using internal implant-abutment connection, five studies on FDPs with external connection, two studies included FDPs, both with internal and with external implant-abutment connection and one studies did not specify the connection type utilized (Table 3&4).

The 5-year failure rates for abutments and FDPs ranged between 0.7% and 4.2%, yet, the difference between internal and external implant-abutment connection did not reach statistical significance (p=0.244 & 0.588) (Table 6). The 5-year complication rate for the total number of technical complications was 9.4% for internal connection and 12.2% for external connection.

The total number of biological complications of the implant-supported FDPs at 5-years was 5.6% for internal implant-abutment connections and 4.8% for external connections, respectively. The difference did, however, not reach statistical significance ($p=0.657$ & 0.753). The 5-year rate of abutment or occlusal screw fracture was significantly ($p=0.010$) higher for implant-supported FDPs with external implant-abutment connections (1.8%) than for internal implant-abutment connections (0.2%). Furthermore, significantly ($p<0.001$) more implants with internal connection (5.6%) were reported to have significant marginal bone loss as compared to implants with external connections (0%). This observation was, however, based on observations of few implant-supported FDPs.

The differences in the complication rates for other technical or biological complications at the internally and externally connected implant-supported FDPs did not reach statistical significance (Table 6).

<u>Abutment material</u>

From the studies included in the present systematic review, 40 reported on titanium abutments, 8 on gold abutments, 5 on metal abutments without specifying which metal was utilized, 15 studies on zirconia-ceramic abutments and 2 studies including a total of 26 implant-supported SCs reported on aluminium oxide abutments. Some of the included studies reported on abutments made from different material groups and one study did not specify the abutment material utilized (Tables 1&2).

The 5-year failure rates for abutments were 1.5% for metal abutments compared with 2.4% for ceramic abutments, and the respective failure rates for the reconstruction were 3.5% when supported by metal abutments and 2.9% when supported by ceramic abutment. The differences in failure rates between the materials did not reach statistical significance ($p=0.220$ & 0.701) (Table 7).

The total number of technical complications was similar for both groups, with a 5-year total complication rate of 11.5% for metal abutments and 11.2% for ceramic abutments, respectively. Regarding technical complications, there were significantly ($p<0.001$) more abutment fractures reported for ceramic abutments, compared with metal abutments. On the other hand, there were significantly more screw loosening reported for metal abutments compared with ceramic abutments.

A significantly ($p=0.029$) higher incidence of biological complications (9.5%) was reported for implants with ceramic abutments, compared with implants with metal abutments (3.7%). Furthermore, significantly more soft tissue recessions were reported for SCs supported with ceramic abutments.

The differences between metal and ceramic abutments regarding other than the above technical and biological complications did not reach statistical significance (Table 7).

<u>Type of retention</u>

The 5-year failure rate for abutment failures was 1.4% for cemented crowns and 1.9% for screw-retained crowns and the 5-year failure rate of the reconstructions was 3.2% for cement-retained SCs and 4.3% for screw-retained SCs. The differences in failure rates between cemented and screw-retained crowns for abutments and SCs did not reach statistical significance ($p=0.491$ & 0.734) (Table 8). The total number of technical complications was higher for screw-retained SCs (15.3%) compared with cemented SCs (8.1%). The difference, however, did not reach statistical significance ($p=0.327$). The number of screw loosening was significantly higher for screw-retained SCs compared with cemented SCs, but ceramic chipping was on the other hand significantly higher for the cemented crowns. The 5-year rate of the total number of biological complications of 6.6%, the rate of soft tissue complication of 2.3% and the rate of substantial marginal bone loss of 1.9% for cemented SCs were significantly ($p<0.001$) higher than the comparable complication rates of 0% for screw-retained SCs. It must be kept in mind that the information on biological complications for screw-retained SCs was limited (Table 8).

Implant position

The included studies were also divided according to the implant position in the dental arch. Fourteen studies, 7 studies testing metal and 7 studies testing ceramic abutments, reported exclusively on implants inserted in the anterior area. Twenty studies, 17 with metal and 3 with ceramic abutments, reported solely on implants placed in the posterior area.

The 5-year abutment failure rate was significantly (p=0.045) higher in the anterior than in the posterior area (2.6% anterior vs. 0.5% posterior). In addition, the 5-year failure rate of the reconstruction was significantly (p=0.014) higher in the anterior compared to the posterior area (3.7% anterior vs. 0.2% posterior) (Table 9).

The total number of technical complications tended to be higher for anterior SCs (8.6%) compared with posterior SCs (4.7%). The difference, however, did not reach statistical significance (p=0.258). Fractures of abutments and crowns as well as loosening of the reconstructions were significantly more frequent in the anterior area.

Finally, the total number of biological complications and the incidence of soft tissue complications and soft tissue recessions were significantly higher in the anterior area than in the posterior area (Table 9).

Study design

The included studies were divided according to the study design applied in a group of 47 prospective studies and a group of 13 retrospective studies. Twelve different parameters for failures and complications were calculated and comparisons made between the different study designs (Table 10). The outcomes reported in prospective and retrospective studies did not exhibit statistically significant differences for any of the 12 parameters tested (Table 10).

Abutment material and implant abutment connection

The extracted data was divided into 4 groups. A group of 1916 metal abutments with internal connection, a group of 1464 metal abutments with external connection, a group of 612 ceramic abutments with internal connection and a group of 348 ceramic abutments with external connection. The failure and complication rates of the different groups were compared with multivariable regression where the outcome for metal abutments with internal connection used as a reference (Tables 11-21).

Regarding implant failures, abutment failures and failure of the reconstructions, there were no significant differences between the four groups (Tables 11-13). The same applied for the total number of technical complications (Table 14), but significantly higher number of biological complications was reported for ceramic abutments with internal connections (Table 15). Abutment fractures were significantly more frequent for ceramic abutments both with internal and external connection (Table 16). The incidence of screw loosening was significantly higher for metal abutments with external implant-abutment connection (Table 17). The fracture rate of the reconstructions was similar for all four groups (Table 18).

The incidence of soft tissue complications was higher for ceramic abutments with internal connection (Table 19) and the incidence of soft tissue recessions was significantly higher for ceramic abutments, both with internal and external connection (Table 20). Furthermore, the rate of implants with marginal bone loss more than 2mm was significantly lower for implants with metal abutments with external connection compared with implants with metal abutments and internal connection and implants with ceramic abutments with external connection (Table 21).

Discussion

The present review showed similar overall survival rates of internally and externally connected implant abutments, with no differences between ceramic and metal abutments. Yet, the review displayed that the implant-abutment connection influenced the technical and biologic outcomes of the implant abutments and the supported reconstructions. In general, the external connections were more prone to specific technical problems, while internal connections were more associated with biologic problems. At both single crowns (SCs) and multiple-unit fixed dental prostheses (FDPs) significantly more abutment screw fractures were observed at external implant-abutment connections. Furthermore, at SCs more screw loosening was reported for abutments/ crowns with external implant abutment connections. With respect to abutment materials, the present review showed higher fracture rates of both externally and internally connected ceramic abutments, as compared to externally and internally connected metal abutments.

Hence, the implant– abutment connection plays an important role for the outcomes of the implant-supported fixed reconstructions as the present review could show. The finding that the predominant technical problem at the external connections was abutment screw loosening and screw fracture is in accordance to previously published literature.

Abutment screw fractures were found in 0.2% and only for externally connected abutments, not for internally connected ones according to a systematic review (Zembic et al. 2014). A higher incidence of screw fractures (0.7% at 3.6 years) and screw loosening (8% at 3.6 years) with this type of implant-abutment connection is supported by other studies (Walton & MacEntee 1997; Kim et al. 2013).

Internal implant-abutment connections have demonstrated significantly higher strength and higher resistance to bending of the abutment-reconstruction complex in laboratory studies before (Norton 2000, Khraisat et al. 2004). As a consequence, it may be assumed that the load on the abutment screw is lower and, hence, the risk for fracture or loosening of the abutment screw is reduced as compared to external connections. This assumption may be confirmed by the results of the present review. Besides the implant-abutment connection, however, several co-founding factors influenced the risk for screw loosening at the fixed implant reconstructions. As shown in a previous review by Theoharidou et al. (2008), anti-rotational features as well as screw preloading torques played an important role to reduce the problems with the abutment screws.

Interestingly, the implant-abutment connections seemed not only to influence the technical outcomes of the implant supported reconstructions, but also influenced their biologic results. At internally connected implant FDPs, bone loss exceeding 2mm was more frequently observed than at externally connected FDPs. As different implant systems with differing designs of the internal connections were included in the present review, numerous factors could contribute to the presented difference. A greater amount of bone loss was reported for implants with matching platforms compared to non-matching ones in several publications (Atieh et al. 2010; Chrcanovic et al. 2015). In addition, the insertion depth of an implant may affect the amount of bone resorption, with less bone loss if the implant is placed at or above the bone crest as compared to below the bone crest (Jung et al. 2008).

A higher incidence of recessions was found around ceramic abutments compared to metal abutments both in a previous (Sailer et al. 2009) and the present review. On the one hand, the higher incidence of soft tissue recessions at internally connected SCs might be related to the abutment material. The manufacturing technique and especially the abutment surface roughness may influence the peri-implant soft tissues (Quirynen et al. 1996). The optimal abutment roughness R_a-value was defined to be 200nm for the establishment of an epithelial seal (Quirynen et al. 1996), whereas a highly polished zirconia surface may induce soft tissue recession (Bollen et al. 1996). On the other hand, it may possible that the implant position might have influenced the incidence of soft tissue recessions, as higher proportion of included implants with internal connection and ceramic abutments were inserted in the anterior area where the buccal bone is often relatively thin and thin soft tissue biotype is frequently observed (Huynh-Ba et al. 2012).

Thus, the abutment material is another factor besides the connection influencing the outcomes of the implant-supported fixed reconstructions. The present review demonstrated significantly higher fracture rates of both, internally and externally connected ceramic abutments as compared to the metal abutments. Problems with the all-ceramic abutments, indeed, have been reported before. Fractures of the internally connected zirconia abutments were reported in 7% - 18% of the cases at 1 - 12 years of function (Carrillo de Albornoz et al. 2014; Passos et al. 2016; Ferrari et al. 2016; Fabbri et al. 2017). Another study pointed out that one has to be careful when using 1-piece zirconia abutments and reduced diameter implants as well as in posterior regions (Gibbs et al. 2002; Nilsson et al. 2017). More recent types of ceramic abutments include metal hybrid secondary components to increase the stability at the level of the connection. Zirconia abutments supported by titanium base abutments showed significantly improved strength in vitro being at the level of metal abutments, as compared to one-piece zirconia abutments (Sailer et al. 2018 in press).

Interestingly, the occurrence of abutment/occlusal screw loosenings and abutment/occlusal screw fractures was significantly more often for metal abutments. Metal abutments are predominantly used in posterior regions, where chewing forces range from 383 N – 678 N for women and 512 N - 1019 N for men (Raadsheer et al. 2004; Cosme et al. 2005; Ikebe et al. 2005).

During function, the forces are transmitted to the crestal bone with the applied load mainly being concentrated in area of the implant-abutment interface. Thus, this zone is critical for the biomechanical behavior of the components and might be the reason for their loosening or fracture. To reduce the risk of technical complications, the use of original components matching with the particular implant manufacturer is highly recommended.

The type of retention for SCs had an influence on different parameters. There were significantly more biological complications for cement-retained SCs. This might be associated with cement remnants, which are known to be a risk factor for inflammation. Cement remnants were detected for SCs cemented on abutments with epi- and submucosal margins either way and both around prefabricated and customized abutments (Linkevicius et al. 2013; Kappel et al. 2016).

In contrast, screw-retained SCs showed significantly more loosening of abutment or occlusal screws and reconstructions. A systematic review comparing cemented and screw-retained implant reconstructions substantiates a higher incidence of technical complications for screw-retained SCs (Sailer et al. 2012).

The main limitation of the present systematic review was, that no RTCs were available addressing the present focussed question, and that the overall conclusions were based on pooled data of different types of implants placed in different positions in the jaws (maxilla, mandible; anterior, posterior). Furthermore, there was a lack of standardized approaches to report biological and technical complications in the available studies. Finally, the included studies often clustered data from patients with different observation periods instead of following patients for a well-defined time period.

Conclusions

For implant-supported SCs, both metal and ceramic abutments with internal and external connections exhibited high survival rate as well as metal abutments with internal and external connection for implant-supported FDPs.

Still, the implant-abutment connection appears to have an influence on the incidence of biological and technical complications. Externally connected abutments encountered more technical problems such as abutment or screw loosening, whereas internally connected abutments were more associated with biologic problems.

Ceramic abutments, both internally end externally connected, demonstrated a significantly higher incidence of abutment fractures than metal abutments.

Finally, cement-retained implant-supported SCs showed significantly more biological complications, in contrast screw-retained crowns had significantly higher incidence of technical complications and screw loosening.

Conflict of interest

The authors have no specific conflict of interest related to the present systematic review.

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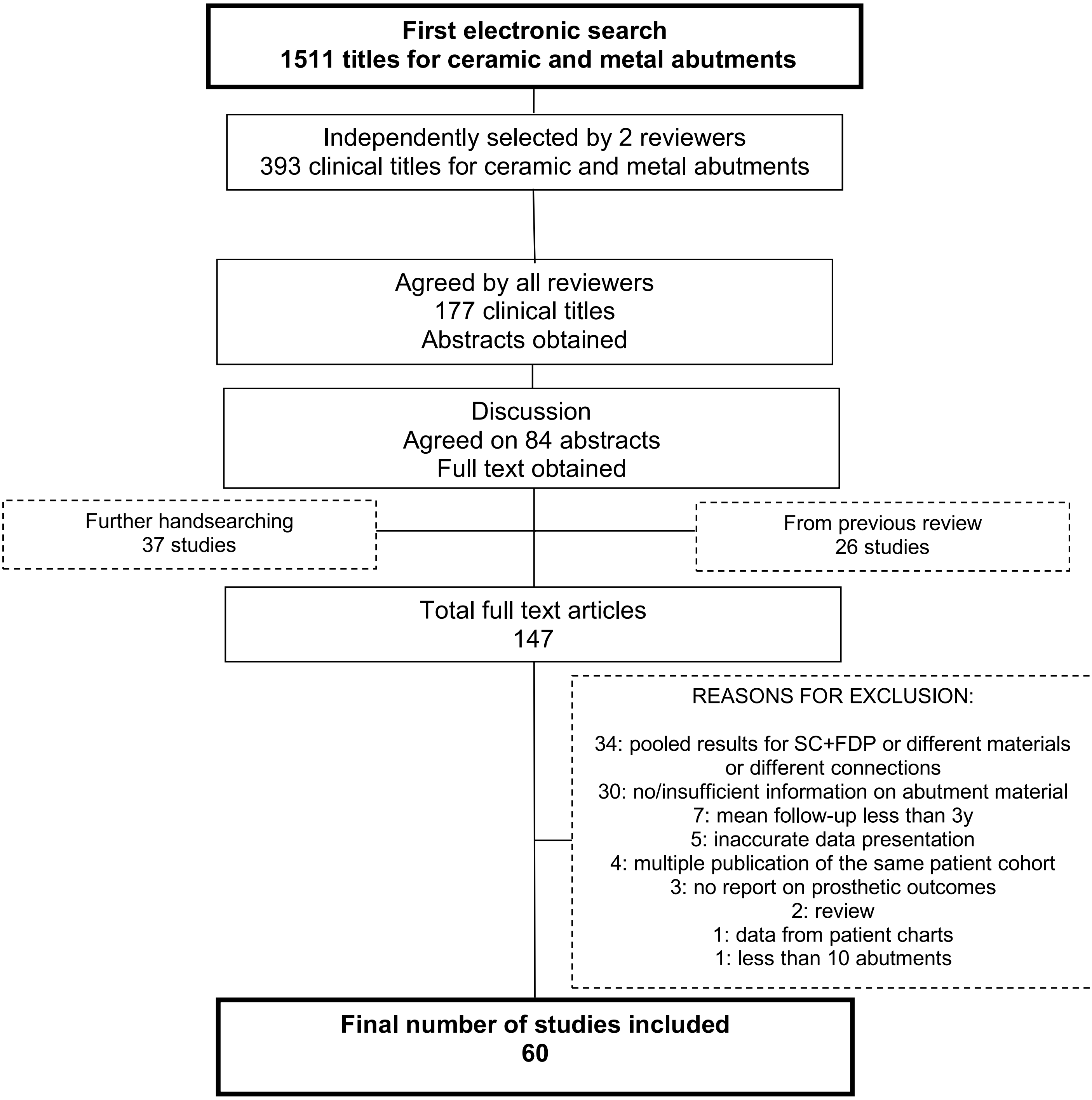

Fig. 1 - Search strategy of the clinical studies

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Results

Study	Year of publication	Study design	Number of patients	Number of abut-ments	Abut-ment material	Type of abutments	Crown material	Clinical setting	Mean follow-up time	Drop out (%)	Quality assessment
Nothdurft et al.	2018	Prospective	26	42	Zirconia	Stock cementable (CERCON abutment)	All-ceramic	n.r.	3	4%	
Nilsson et al.	2017	Prospective	52	69	Zirconia	Custom made abutments were fabricated in yttria-stabilized tetragonal zirconia by a CAD/CAM system (Straumann)	All-ceramic	Specialist clinic	4.5	33%	
Cooper et al.	2016	Prospective RCT	39	47	Titanium	Semi-customized Profile BiAbutment or Direct Abutment (Dentsply)	All-ceramic	University	3	8%	
Nejatidanesh	2016	Retrospective	261	232	Titanium	SynOcta abutments. (Straumann)	All-ceramic	University	4.9	n.r.	
Passos et al.	2016	Retrospective	141	137	Zirconia	Lab adjusted and custom milled	All-ceramic	Private practice	4.8	22%	
Paolantoni et al.	2015	Prospective RCT	65	45	Zirconia	Standard zirconia anchorage. Custom made zirconia anchorage (ART Anchorage. Thommen Medical AG)	All-ceramic	University	4	0%	

Rinke et al.	2015	Retrospective	33	50	Zirconia	Prefabricated Y-TZP abutments (Cercon Balance. Dentsply Implants)	All-ceramic	Private practice	7	18%	
Kolgeci et al.	2014	Retrospective	177	120	Zirconia	Custom-made zirconia abutments	All-ceramic	Private practice	3.3	6%	
Rossi et al.	2014	Prospective cohort	35	40	Titanium	Stock cementable (SynOcta)	Metal-ceramic	Private practice	5	0%	
Sanz et al.	2014	Multicenter Prospective RCT	93	93	Titanium	Standard abutments	Metal-ceramic	n.r.	3	10%	
Berberi et al.	2014	Prospective	20	20	Titanium	Ti-Design. (Astra Tech)	All-ceramic	University	3	0%	
Pozzi et al.	2014	Prospective RCT	34	44	Titanium	NobelProcera	Metal-ceramic	University	3	0%	
Lops et al.	2013	Prospective	85	85	Zirconia	Standard (Ceramic Abutment ST Zir-Design Abutmen). Standard (Profile Bi-Abutment) (Astra Tech)	All-ceramic Metal-ceramic	University	6	2%	
Hosseini et al.	2013	Prospective	59	98	Zirconia Titanium Gold	Stock preparable abutments. cast abutments	All-ceramic Metal-ceramic	University	3.1	0%	
Gotfredsen	2012	Prospective RCT	20	20	Titanium	Standard abutment (Astra Tech)	Metal-ceramic	university	10	10%	
Levine et al.	2012	Prospective	20	21	Titanium	Solid abutments (Straumann)	n.r.	Private practice	5	0%	
Cosyn et al.	2011	Prospective	32	30	Titanium	Standard titanium abutment (Esthetic Abutment. Nobel Biocare)	Metal-ceramic	University	3	22%	
Visser et al.	2011	Prospective RCT	93	92	Titanium	RN SynOcta double screw. with gold coping screwed on top	All-ceramic	University	5	0%	
Buser et al.	2011	Prospective	20	20	Titanium	Milled abutments	All-ceramic	University	3	0%	
Canullo et al.	2010	Multicenter Prospective RCT	32	32	Titanium	Standard titanium abutments	Metal-ceramic	3 Private practices	3	22%	
Payer et al.	2010	Prospective	24	19	Titanium	Esthetic Base. Dentsply Friadent	Metal-ceramic	University	5	11%	
Kinsel et al.	2009	Retrospective cohort	152	390	Titanium	Standard solid abutment	Metal-ceramic	Private practice	5	n.r.	

Canullo	2007	Prospective	25	30	Zirconia	50% smaller diameter. 50% regular diameter	All-ceramic	Private practice	3.3	n.r.	
Cooper et al.	2007	Prospective	48	54	Titanium	ST abutments	All-ceramic Metal-ceramic	University	3	19%	
Bischof et al.	2006	Prospective	212	263	Metal	n.r.	n.r.	Private Practice	5	2%	
Brägger et al.	2005	Prospective	127	69	Titanium Gold	n.r.	n.r.	University	10	n.r.	
Romeo et al.	2004	Prospective	250	123	Titanium	OCTA abutments	Metal-ceramic	University	3.9	12%	
Krennmair et al.	2002	Retrospective	112	146	Metal	Friatec abutments	119 Metal-ceramic 27 All-ceramic	University & private practice	3	n.r.	
Levine et al.	1999	Retrospective	129	174	Titanium	Synocta. Solid abutments (Straumann)	n.r.	Mutlicenter Private Practice	3.3	15%	

Table 1. – Overview of characteristics and materials for studies reporting on implant-supported single crowns (SCs) with internal implant-abutment connection.

High methodological quality
Medium methodological quality
Low methodological quality

Study	Year of publication	Study design	Number of patients	Number of abut-ments	Abut-ment material	Type of abutments	Crown material	Clinical setting	Mean follow-up time	Drop out (%)	Quality assessment
Cooper et al.	2016	Prospective RCT	39	46	Titanium	Semi-customized GingiHue Post Abutment (Biomet 3i)	All-ceramic	University	3	8%	
Canullo et al.	2016	Prospective RCT	35	30	Titanium	Customized grade 5 titanium with platform switching	NR	University	5	14%	
Fenner et al.	2016	Prospective RCT	36	36	Titanium Aluminium oxide	Titanium (synOcta cementable abutment & individualized Al2O3 abutments (synOcta In-Ceram blank) (Straumann)	All-ceramic Metal-ceramic	University	7.2	22%	
Passos et al.	2016	Retrospective	141	21	Zirconia	Pre-fabricated abutments	All-ceramic	Private practice	4.8	22%	
Vigolo et al.	2015	Retrospective	22	66	Gold	Custom gold abutments (SGUC A1C. Biomet/3i)	Metal-ceramic	University and Private Practice	10	18%	

Zembic et al.	2014	Prospective	27	54	Zirconia	Customized yttria-stabilized zirconia ingot	All-ceramic	University	11.3	41%	
Pozzi A et al.	2014	Prospective RCT	34	44	Titanium	NobelProcera	Metal-ceramic	University	3	0%	
Kim et al.	2013	Prospective	213	133	Zirconia	Alumina-toughened zirconia abutments (ZirAce¨. Acucera. Pocheon. Korea)	n.r.	University	3.6	n.r.	
Zembic et al.	2013	Prospective RCT	22	20	Zirconia	Customized cadcam (Procera)	All-ceramic Metal-ceramic	University	5.6	50%	
Vigolo et al.	2012	Split mouth Prospective RCT	18	36	Gold	Customized. machined UCLA	Metal-ceramic	University	10	11%	
Bergenblock et al.	2012	Prospective	57	65	Titanium	CeraOne. Nobel Biocare	62 All-ceramic 3 Metal-ceramic	Specialist clinic	18.4	18%	
Calandriello & Tomatis.	2011	Prospective	33	40	n.r.	Procera. Nobel Biocare	All-ceramic	Private practice	5	0%	
Bonde et al.	2010	Prospective RCT	51	55	Titanium	CeraOne. Nobel Biocare	All-ceramic	University & private practice	10	6%	
MacDonald et al.	2009	Prospective	20	20	Titanium	Cast UCLA . Stock TI	Metal-ceramic	University	8	15%	
Vigolo & Givani	2009	Prospective	n.r.	182	Gold	Platform switch, standard diameter. UCLA & matching, wide diameter UCLA; (3i/ Implant Innovations)	Metal-ceramic	Private practice	5	0%	
Jemt	2009	Retrospective	35	41	Titanium	TiAdapt & CeraOne (Nobel Biocare)	Metal-ceramic	University	20	31%	
Vigolo et al.	2006	Prospective RCT	20	40	Titanium	Procera titanium. UCLA	Metal-ceramic	University	4	0%	
Glauser et al.	2004	Prospective	27	54	Zirconia	Densely sintered prototype ingots. copy-milling (Wohlwend)	All-ceramic	University	4.1	n.r.	
Muche et al.	2003	Retrospective	76	205	Metal	UCLA	Metal-ceramic	University	3	n.r.	
Andersson et al.	2001	Prospective RCT	15	20	Alumini a	CerAdapt. CeraOne	All-ceramic	Specialist clinic	3	0%	
Bianco et al.	2000	Retrospective	214	252	Titanium	Regular. STR. CeraOne. Esthetic one. others	50 All-ceramic Metal-ceramic Metal	Mutlicenter Private Practice	8	4%	
Wannfors & Smedberg	1999	Prospective	69	80	Titanium Gold	UCLA. CeraOne	8 Metal-ceramic 36 Metal-acrylic	Specialized Clinic	3	4%	
Scheller et al.	1998	Multicenter Prospective	82	99	Titanium	CeraOne	All-ceramic	Mutlicenter Private Practice	3.7	30%	
Avivi-Arber et al.	1996	Prospective	41	49	Titanium	Standard CeraOne, Angulated	Metal-ceramic	University	4	12%	
Henry et al.	1996	Prospective	92	107	Titanium	Standard Abutments	Metal-ceramic Metal-acrylic	Mutlicenter Private Practice	5	9%	

Degidi et al.*	2009	Prospective RCT	60	60	Titanium	n.r.	Metal-ceramic	Private practice	3	0%	
Kreissl et al.*	2007	Prospective	76	46	Metal	UCLA abutments	Metal-ceramic	University	5	n.r.	

Table 2. – Overview of characteristics and materials for studies reporting on implant-supported single crowns (SCs) with external implant-abutment connection.

- * The study did not specify the implant abutment connection used.

High methodological quality
Medium methodological quality
Low methodological quality

Study	Year of publi-cation	Study design	Number of patients	Number of abut-ments	Abut-ment material	Type of abutments	Number of FDPs	FDP material	Clinical setting	Mean follow-up time	Drop out (%)	Quality assess-ment
Konstantinidis et al.	2015	Prospective	7	15	Zirconia	Individual zirconia abutments cemented on Titanium-base (Wieland)	6	Zirconia-ceramic	University	3	7%	
Larsson et al.	2010	Prospective RCT	18	66	Titanium	Customized, Profile BiAbutment (Astra Tech)	n.r.	Zirconia-ceramic	University	5	0%	
Payer et al.	2010	Prospective	24	21	Titanium	EstheticBase (Dentsply Friadent)	n.r.	Metal-ceramic	University	5	8%	
Brägger et al.	2005	Prospective	127	69	Titanium Gold	n.r.	33	Metal-ceramic	n.r.	10	0%	
Romeo et al.	2004	Prospective	250	336	Titanium	OCTA abutments	137	n.r.	n.r.	3.9	12%	
Preiskel & Tsolka*	2004	Retrospective	44	286	Titanium	DIA, TiAdapt, Replace, EstheticCone, MirusCone & angulated abutment	78	n.r.	Specialized clinic	7.2	1%	
Romeo et al.*	2003	Prospective	38	100	Titanium Gold	OCTA, AurAdapt, TiAdapt, EstheticCone	49	Metal-ceramic	University,Specialized clinic	4	0%	

Table 3. – Overview of characteristics and materials for studies reporting on implant-supported fixed dental prostheses (FDPs) with internal implant-abutment connection.

- * The study included both implants with internal and implants with external implant-abutment connection.

High methodological quality
Medium methodological quality
Low methodological quality

Study	Year of publication	Study design	Number of patients	Number of abutments	Abutment material	Type of abutments	Number of FDPs	FDP material	Clinical setting	Mean follow-up time	Drop out (%)	Quality assessment
Vigolo et al.	2015	Retrospective	22	66	Gold	Custom gold abutments, SGUCA1C (Biomet/3i)	20	Metal-ceramic	University Private Practice	10	9%	
Kreissl et al. **	2007	Prospective	76	159	Metal	UCLA abutments	66	Metal-ceramic	University	5	0%	
Preiskel & Tsolka*	2004	Retrospective	44	286	Titanium	DIA, TiAdapt, Replace, EsthetiCone, MirusCone & angulated abutment	78	n.r.	Specialized clinic	7.2	1%	
Andersson et al.	2003	Prospective RCT	32	105	Titanium	Titanium (Nobel Biocare)	17	n.r.		5	n.r.	
Jemt et al.	2003	Prospective	42	170	Titanium	Standard Abutments	63	Metal-ceramic	Multicenter Private Practice	5	17%	
Romeo et al.*	2003	Prospective	38	100	Titanium Gold	OCTA, AurAdapt, TiAdapt, EsthetiCone	49	Metal-ceramic	University, Specialized clinic	4	0%	
Wyatt & Zarb	1998	Retrospective	77	230	Titanium	Standard, EsthetiCone, angulated abutments	97	Metal-ceramic Metal-acrylic	University	5.4	6%	

Table 4. – Overview of characteristics and materials for studies reporting on implant-supported fixed dental prostheses (FDPs) with external implant-abutment connection.

- * The study included both implants with internal and implants with external implant-abutment connection.
- ** The study did not specify the implant abutment connection used.

High methodological quality
Medium methodological quality
Low methodological quality

Implant – abutment connection for SCs

Failures Complication	Number of SCs	Estimated annual complication or failure rates (95 % CI)	Cumulative 5 year complication or failure rates (95 % CI)	Number of SCs	Estimated annual complication or failure rates (95 % CI)	Cumulative 5 year complication or failure rates (95 % CI)	p-value
		Internal - connection		External - connection			
Abutment failure	1831	**0.46* (0.30-0.68)**	**2.3%* (1.5%-3.4 %)**	1683	**0.27* (0.14-0.51)**	**1.3%* (0.7%-2.5 %)**	p=0.161
Failure of the reconstruction	2005	**0.49* (0.31-0.79)**	**2.4%* (1.5%-3.9 %)**	1442	**0.87* (0.36-2.15)**	**4.3%* (1.8%-10.2 %)**	p=0.266
Total number of technical complications	1770	**2.14* (1.65-2.77)**	**10.1%* (7.9%-12.9 %)**	1480	**2.64* (1.65-4.23)**	**12.4%* (7.9%-19.0 %)**	p=0.431
Abutment fracture	1924	**0.14* (0.05-0.40)**	**0.7%* (0.3%-2.0 %)**	1312	**0.37* (0.09-1.60)**	**0.4%* (0.09%-1.6 %)**	p=0.480
Abutment or occlusal screw loosening	1767	**0.24* (0.13-0.47)**	**1.2%* (0.6%-2.3 %)**	1610	**0.98* (0.53-1.80)**	**4.8%* (2.6%-8.6 %)**	p=0.002
Fracture of the reconstruction	1713	**0.22* (0.11-0.43)**	**1.1%* (0.6%-2.1 %)**	1232	**0.19* (0.07-0.53)**	**1.0%* (0.4%-2.6 %)**	p=0.833
Ceramic chipping	1911	**0.99* (0.64-1.52)**	**4.8%* (3.2%-7.3 %)**	1309	**0.30* (0.18-0.52)**	**1.5%* (0.9%-2.6 %)**	p=0.001
Loosening of the reconstruction	1743	**0.65* (0.30-1.42)**	**3.2%* (1.5%-6.9 %)**	1328	**0.48* (0.21-1.11)**	**2.4%* (1.0%-5.4 %)**	p=0.598
Total number of biological complications	1194	**1.39* (0.59-3.25)**	**6.7%* (2.9%-15.0 %)**	1296	**0.87* (0.49-1.54)**	**4.3%* (2.4%-7.4 %)**	p=0.364
Soft tissue complications	1011	**0.47* (0.14-1.62)**	**2.3%* (0.7%-7.8 %)**	1160	**0.35* (0.16-0.77)**	**1.8%* (0.8%-3.8 %)**	p=0.689
Bone loss more than 2mm	849	**0.58* (0.22-1.52)**	**2.9%* (1.1%-7.3 %)**	1193	**0.30* (0.15-0.61)**	**1.5%* (0.7%-3.0 %)**	p=0.263
Soft tissue recessions	529	**2.14* (0.71-6.42)**	**10.1%* (3.5%-27.4 %)**	579	**0.50* (0.17-1.49)**	**2.5%* (0.8%-7.2 %)**	p=0.060

Table 5. – Comparing annual failure and complication rates of SCs supported by implants with internal or external connection.

- Based on robust Poisson regression.

Implant – abutment connection for FDPs

Failures Complication	Number of FDPs abut-ments	Estimated annual complication or failure rates (95 % CI)	Cumulative 5 year complication or failure rates (95 % CI)	Number of FDPs abut-ments	Estimated annual complication or failure rates (95 % CI)	Cumulative 5 year complication or failure rates (95 % CI)	p-value
		Internal - connection		External - connection			

Abutment failure	507	**0.56* (0.23-1.39)**	**2.8%* (1.1%-6.7 %)**	341	**0.15* (0.02-1.43)**	**0.7%* (0.1%-6.9 %)**	p=0.244
Failure of the reconstruction	507	**0.60* (0.27-1.37)**	**3.0%* (1.3%-6.6 %)**	466	**0.87* (0.27-2.80)**	**4.2%* (1.3%-13.1 %)**	p=0.588
Total number of technical complications	471	**1.97* (0.80-4.85)**	**9.4%* (3.9%-21.5 %)**	571	**2.59* (1.00-6.74)**	**12.2%* (4.9%-28.6 %)**	p=0.657
Abutment or occlusal screw fracture	471	**0.04* (0.01-0.16)**	**0.2%* (0.06%-0.8 %)**	571	**0.37* (0.11-1.25)**	**1.8%* (0.5%-6.0 %)**	p=0.010
Abutment or occlusal screw loosening	471	**0.17* (0.10-0.31)**	**0.9%* (0.5%-1.5 %)**	571	**0.40* (0.14-1.11)**	**2.0%* (0.7%-5.4 %)**	p=0.136
Fracture of the reconstruction	486	**0.04* (0.01-0.15)**	**0.2%* (0.06%-0.7 %)**	571	**0.03* (0.004-0.24)**	**0.2%* (0.02%-1.2 %)**	p=0.781
Ceramic chipping	486	**1.39* (0.29-6.65)**	**6.7%* (1.4%-28.3 %)**	571	**1.04* (0.45-2.41)**	**5.1%* (2.2%-11.3 %)**	p=0.728
Loosening of the reconstruction	486	**0.67* (0.25-1.81)**	**3.3%* (1.2%-8.6 %)**	571	**0.76* (0.27-2.17)**	**3.7%* (1.3%-10.3 %)**	p=0.856
Total number of biological complications	69	**1.16* (0.50-2.27)**	**5.6%* (2.5%-10.7 %)**	571	**0.98* (0.33-2.91)**	**4.8%* (1.6%-13.6 %)**	p=0.753
Bone loss more than 2mm	69	**1.16* (0.50-2.27)**	**5.6%* (2.5%-10.7 %)**	341	**0***	**0%***	p<0.001

Table 6. – Comparing annual failure and complication rates of FDPs supported by implants with internal or external connection.

- Based on robust Poisson regression.

Abutment material

Failures Complication	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	p-value
		Metal - abutments		**Ceramic - abutments**			
Abutment failure	2554	**0.31* (0.20-0.49)**	**1.5%* (1.0%-2.4 %)**	929	**0.48* (0.28-0.87)**	**2.4%* (1.4%-4.2 %)**	p=0.220
Failure of the reconstruction	2543	**0.71* (0.34-1.49)**	**3.5%* (1.7%-7.2 %)**	910	**0.59* (0.31-1.13)**	**2.9%* (1.5%-5.5 %)**	p=0.701
Total number of technical complications	2516	**2.45.* (1.74-3.44)**	**11.5%* (8.3%-15.8 %)**	800	**2.39* (1.55-3.69)**	**11.2%* (7.4%-16.8 %)**	p=0.931

Abutment fracture	2382	**0.02* (0.004-0.068)**	**0.08%* (0.02%-0.34%)**	920	**0.37* (0.40-2.95)**	**1.8%* (0.9%-3.9%)**	p<0.001
Abutment or occlusal screw loosening	2776	**0.78* (0.44-1.38)**	**3.8%* (2.2%-6.6%)**	667	**0.29* (0.16-0.52)**	**1.5%* (0.8%-2.6%)**	p=0.018
Fracture of the reconstruction	2224	**0.21* (0.11-0.42)**	**1.0%* (0.5%-2.1%)**	787	**0.18* (0.07-0.51)**	**0.9%* (0.3%-2.5%)**	p=0.825
Ceramic chipping	2559	**0.62* (0.35-1.12)**	**3.1%* (1.7%-5.5%)**	667	**0.79* (0.38-1.66)**	**3.9%* (1.9%-8.0%)**	p=0.618
Loosening of the reconstruction	2424	**0.61* (0.32-1.16)**	**3.0%* (1.6%-5.6%)**	667	**0.38* (0.15-1.00)**	**1.9%* (0.7%-4.9%)**	p=0.411
Total number of biological complications	1760	**0.75* (0.45-1.27)**	**3.7%* (2.2%-6.2%)**	750	**2.00* (0.97-4.12)**	**9.5%* (4.7%-18.6%)**	p=0.029
Soft tissue complications	1579	**0.36* (0.18-0.74)**	**1.8%* (0.9%-3.7%)**	592	**0.50* (0.11-2.18)**	**2.5%* (0.6%-10.3%)**	p=0.687
Bone loss more than 2mm	1639	**0.32* (0.14-0.72)**	**1.6%* (0.7%-3.5%)**	363	**0.50* (0.20-1.25)**	**2.5%* (1.0%-6.1%)**	p=0.444
Soft tissue recessions	760	**0.30* (0.11-0.84)**	**1.5%* (0.5%-4.1%)**	348	**2.70* (1.17-6.22)**	**12.6%* (5.7%-26.7%)**	p=0.001

Table 7. – Comparing annual failure and complication rates of SCs supported by metal or ceramic implant abutments.

- Based on robust Poisson regression.

Type of retention

Failures Complication	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	p-value
		Cement retained		**Screw retained**			
Abutment failure	2212	**0.28* (0.17-0.46)**	**1.4%* (0.9%-2.3%)**	428	**0.38* (0.18-0.78)**	**1.9%* (0.9%-3.8%)**	p=0.491
Failure of the reconstruction	2179	**0.66* (0.29-1.47)**	**3.2%* (1.5%-7.1%)**	472	**0.87* (0.18-4.17)**	**4.3%* (0.9%-18.8%)**	p=0.734
Total number of technical complications	1881	**1.70* (1.30-2.21)**	**8.1%* (6.3%-10.5%)**	83	**3.31* (0.78-14.15)**	**15.3%* (3.8%-50.7%)**	p=0.327
Abutment fracture	2142	**0.10* (0.03-0.29)**	**0.5%* (0.2%-1.4%)**	408	**0***	**0%***	p<0.001
Abutment or occlusal screw loosening	2210	**0.29* (0.17-0.50)**	**1.5%* (0.9%-2.5%)**	127	**1.82* (0.58-5.71)**	**8.7%* (2.8%-24.8%)**	p=0.002
Fracture of the reconstruction	2128	**0.17* (0.07-0.37)**	**0.8%* (0.4%-1.8%)**	312	**0.33* (0.08-1.27)**	**1.6%* (0.4%-6.1%)**	p=0.360

Ceramic chipping	2282	**0.75* (0.46-1.24)**	**3.7%* (2.3%-6.0%)**	129	**0.27* (0.13-0.58)**	**1.3%* (0.6%-2.8%)**	p=0.015
Loosening of the reconstruction	2060	**0.20* (0.10-0.41)**	**1.0%* (0.5%-2.1%)**	332	**1.99* (0.25-16.04)**	**9.5%* (1.2%-55.2%)**	p=0.022
Total number of biological complications	1623	**1.36* (0.77-2.41)**	**6.6%* (3.8%-11.3%)**	127	**0***	**0%***	p<0.001
Soft tissue complications	1432	**0.47* (0.23-0.96)**	**2.3%* (1.1%-4.7%)**	127	**0***	**0%***	p<0.001
Bone loss more than 2mm	1278	**0.38* (0.16-0.92)**	**1.9%* (0.8%-4.5%)**	83	**0***	**0%***	p<0.001
Soft tissue recessions	578	**1.52* (0.53-4.36)**	**7.3%* (2.6%-19.6%)**	83	**0.24* (0.02-2.96)**	**1.2%* (0.1%-13.6%)**	p=0.124

Table 8. – Comparing annual failure and complication rates of <u>cement retained and screw retained</u> implant-supported SCs.

- Based on robust Poisson regression.

Implant position – Anterior vs. Posterior

Failures Complication	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	p-value
		Anterior implants		**Posterior implants**			
Abutment failure	473	**0.52* (0.24-1.14)**	**2.6%* (1.2%-5.5%)**	765	**0.10* (0.02-0.42)**	**0.5%* (0.1%-2.1%)**	p=0.045
Failure of the reconstruction	473	**0.75* (0.33-1.71)**	**3.7%* (1.6%-8.2%)**	765	**0.05* (0.006-0.38)**	**0.2%* (0.03%-1.9%)**	p=0.014
Total number of technical complications	496	**1.80* (1.23-2.64)**	**8.6%* (6.0%-12.4%)**	540	**0.96* (0.34-2.72)**	**4.7%* (1.7%-12.7%)**	p=0.258
Abutment fracture	426	**0.38* (0.15-0.92)**	**1.9%* (0.8%-4.5%)**	765	**0***	**0%***	p<0.001
Abutment or occlusal screw loosening	144	**0.32* (0.16-0.64)**	**1.6%* (0.8%-3.2%)**	205	**0.28* (0.06-1.24)**	**1.4%* (0.3%-6.0%)**	p=0.849
Fracture of the reconstruction	338	**0.13* (0.04-0.46)**	**0.6%* (0.2%-2.3%)**	633	**0***	**0%***	p<0.001
Ceramic chipping	486	**0.48* (0.19-1.21)**	**2.4%* (1.0%-5.9%)**	628	**0.38* (0.08-1.77)**	**1.9%* (0.4%-8.5%)**	p=0.798
Loosening of the reconstruction	486	**0.44* (0.18-1.07)**	**2.2%* (0.9%-5.2%)**	677	**0***	**0%***	p<0.001

Total number of biological complications	226	**2.71* (1.62-4.54)**	**12.7%* (7.8%-20.3 %)**	480	**0.15* (0.05-0.46)**	**0.7%* (0.2%-2.3 %)**	p<0.001
Soft tissue complications	449	**0.78* (0.19-3.16)**	**3.8%* (1.0%-14.6 %)**	451	**0.04* (0.005-0.29)**	**0.2%* (0.02%-1.4 %)**	p=0.014
Bone loss more than 2mm	389	**0.47* (0.18-1.22)**	**2.3%* (0.9%-5.9 %)**	546	**0.22* (0.03-1.74)**	**1.1%* (0.1%-8.4 %)**	p=0.499
Soft tissue recessions	268	**2.32* (0.98-5.53)**	**11.0%* (4.8%-24.2 %)**	432	**0***	**0%***	p<0.001

Table 9. – Comparing annual failure and complication rates of implant-supported SCs inserted in the anterior or posterior area.

- Based on robust Poisson regression.

Study design – Prospective vs. Retrospective

Failures Complication	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	Number of SCs	**Estimated annual complication or failure rates (95 % CI)**	**Cumulative 5 year complication or failure rates** (95 % CI)	p-value
		Prospective studies		**Retrospective studies**			
Abutment failure	2269	**0.37* (0.22-0.62)**	**1.8%* (1.1%-3.1 %)**	1224	**0.31* (0.21-0.47)**	**1.6%* (1.0%-2.3 %)**	p=0.608
Failure of the reconstruction	2269	**0.81* (0.40-1.64)**	**4.0%* (2.0%-7.9 %)**	1247	**0.39* (0.23-0.66)**	**1.9%* (1.1%-3.2 %)**	p=0.099
Total number of technical complications	2018	**2.61* (1.74-3.90)**	**12.2%* (8.3%-17.7 %)**	1338	**2.13* (1.54-2.93)**	**10.1%* (7.4%-13.6 %)**	p=0.430
Abutment fracture	2095	**0.10* (0.03-0.32)**	**0.5%* (0.2%-1.6 %)**	1247	**0.12* (0.03-0.42)**	**0.6%* (0.2%-2.1 %)**	p=0.842
Abutment or occlusal screw loosening	2104	**0.68* (0.30-1.55)**	**3.4%* (1.5%-7.5 %)**	1379	**0.67* (0.38-1.16)**	**3.3%* (1.9%-5.6 %)**	p=0.956
Fracture of the reconstruction	1978	**0.22* (0.10-0.45)**	**1.1%* (0.5%-2.2 %)**	1073	**0.17* (0.07-0.41)**	**0.8%* (0.4%-2.0 %)**	p=0.661
Ceramic chipping	1712	**0.59* (0.37-0.92)**	**2.9%* (1.9%-4.5 %)**	1554	**0.73* (0.32-1.65)**	**3.6%* (1.6%-7.9 %)**	p=0.627
Loosening of the reconstruction	1957	**0.41* (0.18-0.96)**	**2.1%* (0.9%-4.7 %)**	1156	**0.78* (0.37-1.68)**	**3.8%* (1.8%-8.0 %)**	p=0.262
Total number of biological complications	1600	**0.98* (0.56-1.70)**	**4.8%* (2.8%-8.1 %)**	950	**1.19* (0.45-3.16)**	**5.8%* (2.2%-14.6 %)**	p=0.724
Soft tissue complications	1379	**0.49* (0.22-1.06)**	**2.4%* (1.1%-5.2 %)**	792	**0.27* (0.08-0.86)**	**1.3%* (0.4%-4.2 %)**	p=0.383
Bone loss more than 2mm	1487	**0.48* (0.23-0.98)**	**2.4%* (1.2%-4.8 %)**	555	**0.21* (0.10-0.44)**	**1.0%* (0.5%-2.2 %)**	p=0.102

Soft tissue recessions	445	**0.72*** **(0.34-1.56)**	**3.6%*** **(1.7%-7.5 %)**	663	**1.12*** **(0.24-5.22)**	**5.4%*** **(1.2%-23.0 %)**	p=0.603

Table 10. – Comparing annual failure and complication rates of implant-supported SCs inserted in prospective or retrospective studies.

- Based on robust Poisson regression.

Abutment material and implant abutment connection

Type of abutment material and connection	**Total number of implants**	**Estimated annual implant failure rate***	5 year failure summary estimate* (95 % CI)	**Relative failure rate****	**p-value****
Metal abutments with internal connection	1433	0.57 (0.36-0.90)	2.8% (1.8%-4.4%)	1.00 (Ref.)	
Metal abutments with external connection	1384	0.49 (0.32-0.73)	2.4% (1.6%-3.6%)	0.86 (0.47-1.56)	p=0.614
Ceramic abutments with internal connection	582	0.20 (0.05-0.79)	1.0% (0.2%-3.9%)	0.35 (0.09-1.39)	p= 0.136
Ceramic abutments with external connection	254	0.31 (0.07-1.32)	1.5% (0.4%-6.4%)	0.54 (0.14-2.08)	p=0.371

Table 11. – Summary of annual failure rates, relative failure rates and failure estimates of implants supporting SCs with metal-abutments with internal connection as reference.

* Based on robust Poisson regression.

** Based on multivariable robust Poisson regression.

Type of abutment material and connection	**Total number of abutments**	**Estimated annual abutment failure rate***	5 year failure summary estimate* (95 % CI)	**Relative failure rate****	**p-value****
Metal abutments with internal connection	1219	0.40 (0.24-0.68)	2.0% (1.2%-3.3%)	1.00 (Ref.)	
Metal abutments with external connection	1335	0.25 (0.12-0.54)	1.3% (0.6%-2.6%)	0.64 (0.26-1.57)	p=0.326
Ceramic abutments with internal connection	612	0.57 (0.32-1.03)	2.8% (1.6%-5.0%)	1.43 (0.66-3.07)	p=0.361
Ceramic abutments with external connection	308	0.39 (0.10-1.53)	2.0% (0.5%-7.4%)	0.98 (0.26-3.72)	p=0.981

Table 12. – Summary of annual failure rates, relative failure rates and failure estimates for abutments supporting implant SCs with metal-abutments with internal connection as reference.

* Based on robust Poisson regression.

** Based on multivariable robust Poisson regression.

Type of abutment material and connection	Total number of reconstructions	Estimated annual reconstruction failure rate*	5 year failure summary estimate* (95 % CI)	Relative failure rate**	p-value**
Metal abutments with internal connection	1393	0.40 (0.23-0.69)	2.0% (1.1%-3.4%)	1.00 (Ref.)	
Metal abutments with external connection	1104	1.03 (0.39-2.72)	5.0% (1.9%-12.7%)	2.60 (0.86-7.82)	p=0.089
Ceramic abutments with internal connection	612	0.72 (0.36-1.47)	3.6% (1.8%-7.1%)	1.83 (0.77-4.38)	p=0.174
Ceramic abutments with external connection	298	0.39 (0.10-1.53)	2.0% (0.5%-7.4%)	1.00 (0.26-3.80)	p=0.996

Table 13. – Summary of annual failure rates, relative failure rates and failure estimates for implant-supported SCs with metal-abutments with internal connection as reference.
* Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	Total number of abutments	Estimated annual complication rate*	5 year complication summary estimate* (95 % CI)	Relative failure rate**	p-value**
Metal abutments with internal connection	1278	2.02 (1.43-2.86)	9.6% (6.9%-13.3%)	1.00 (Ref.)	
Metal abutments with external connection	1132	2.81 (1.63-4.83)	13.1% (7.8%-21.5%)	1.39 (0.74-2.61)	p=0.311
Ceramic abutments with internal connection	492	2.42 (1.70-3.46)	11.4% (8.1%-15.9%)	1.20 (0.74-1.94)	p=0.460
Ceramic abutments with external connection	308	2.50 (0.90-6.89)	11.7% (4.4%-29.1%)	1.23 (0.46-3.28)	p=0.674

Table 14. – Summary of annual complication rates, relative complication rates and estimates for total number of technical complication for implant-supported SCs with metal-abutments with internal connection as reference.
* Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	Total number of abutments	Estimated annual complication rate*	5 year complication summary estimate* (95 % CI)	Relative failure rate**	p-value**
Metal abutments with internal connection	752	0.70 (0.24-1.99)	3.4% (1.2%-9.5%)	1.00 (Ref.)	
Metal abutments with external connection	948	0.79 (0.43-1.48)	3.9% (2.1%-7.1%)	1.14 (0.35-3.74)	p=0.829
Ceramic abutments with internal connection	442	2.66 (1.21-5.86)	12.5% (5.9%-25.4%)	3.82 (1.08-13.5)	p=0.037
Ceramic abutments with external connection	308	1.38 (0.44-4.32)	6.7% (2.2%-19.4%)	1.98 (0.46-8.45)	p=0.356

Table 15. – Summary of annual complication rates, relative complication rates and estimates for total number of biological complication for implant-supported SCs with metal-abutments with internal connection as reference.
*   Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	Total number of abutments	Estimated annual abutment fracture rate*	5 year complication summary estimate* (95 % CI)	Relative failure rate**	p-value**
Metal abutments with internal connection	1312	0.03 (0.008-0.15)	0.2% (0.04%-0.8%)	1.00 (Ref.)	
Metal abutments with external connection	964	0	0%	0.00000023	p<0.001
Ceramic abutments with internal connection	612	0.38 (0.15-0.99)	1.9% (0.7%-4.8%)	11.1 (2.0-62.6)	p=0.006
Ceramic abutments with external connection	308	0.39 (0.10-1.53)	2.0% (0.5%-7.4%)	11.5 (1.7-77.6)	p=0.012

Table 16. – Summary of annual complication rates, relative complication rates and estimates for abutment fractures for implant-supported SCs with metal-abutments with internal connection as reference.
*   Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	Total number of abutments	Estimated annual complication rate*	5 year complication summary estimate* (95 % CI)	Relative failure rate**	p-value**
Metal abutments with internal connection	1275	0.23 (0.10-0.57)	1.2% (0.5%-2.8%)	1.00 (Ref.)	
Metal abutments with external connection	1395	1.08 (0.57-2.05)	5.3% (2.8%-9.7%)	4.62 (1.58-13.54)	p=0.005
Ceramic abutments with internal connection	492	0.27 (0.12-0.63)	1.3% (0.6%-3.1%)	1.15 (0.35-3.75)	p=0.821
Ceramic abutments with external connection	175	0.38 (0.18-0.81)	1.9% (0.9%-4.0%)	1.63 (0.55-4.87)	p=0.380

Table 17. – Summary of annual complication rates, relative complication rates and estimates for screw loosening for implant-supported SCs with metal-abutments with internal connection as reference.
* Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	Total number of abutments	Estimated annual complication rate*	5 year complication summary estimate* (95 % CI)	Relative failure rate**	p-value**
Metal abutments with internal connection	1101	0.20 (0.08-0.50)	1.0% (0.4%-2.5%)	1.00 (Ref.)	
Metal abutments with external connection	1017	0.24 (0.09-0.64)	1.2% (0.4%-3.1%)	1.20 (0.32-4.57)	p=0.786
Ceramic abutments with internal connection	612	0.27 (0.10-0.72)	1.3% (0.5%-3.5%)	1.36 (0.37-5.06)	p=0.645
Ceramic abutments with external connection	175	0	0%	0.00000033	p<0.001

Table 18. – Summary of annual complication rates, relative complication rates and estimates for fracture of implant-supported SCs with metal-abutments with internal connection as reference.
* Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	Total number of abutments	Estimated annual complication rate*	5 year complication summary estimate* (95 % CI)	Relative failure rate**	p-value**

Metal abutments with internal connection	706	0.18 (0.03-1.12)	0.9% (0.1%-5.4%)	1.00 (Ref.)	
Metal abutments with external connection	873	0.44 (0.19-0.99)	2.2% (1.0%-4.8%)	2.44 (0.35-16.9)	p=0.367
Ceramic abutments with internal connection	305	1.15 (0.35-3.79)	5.6% (1.7%-17.3 %)	6.39 (0.79-51.68)	p=0.082
Ceramic abutments with external connection	287	0	0%	0.000000048	p<0.001

Table 19. – Summary of annual complication rates, relative complication rates and estimates for <u>soft tissue complications</u> for implant-supported SCs with metal abutments with internal connection as reference.
*   Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	**Total number of abutments**	**Estimated annual complication rate***	5 year complication summary estimate* (95 % CI)	**Relative failure rate****	**p-value****
Metal abutments with internal connection	266	0.62 (0.28-1.40)	3.1% (1.4%-6.8%)	1.00 (Ref.)	
Metal abutments with external connection	494	0.23 (0.06-0.85)	1.2% (0.3%-4.2%)	0.38 (0.09-1.62)	p=0.189
Ceramic abutments with internal connection	263	3.23 (1.25-8.32)	14.9% (6.1%-34.0%)	5.19 (1.69-15.92)	p=0.004
Ceramic abutments with external connection	85	1.97 (0.64-6.05)	9.4% (3.2%-26.1%)	3.16 (1.05-9.52)	p=0.041

Table 20. – Summary of annual complication rates, relative complication rates and estimates for <u>soft tissue recessions</u> for implant-supported SCs with metal-abutments with internal connection as reference.
*   Based on robust Poisson regression.
** Based on multivariable robust Poisson regression.

Type of abutment material and connection	**Total number of abutments**	**Estimated annual complication rate***	5 year complication summary estimate* (95 % CI)	**Relative failure rate****	**p-value****
Metal abutments with internal connection	604	0.73 (0.25-2.08)	3.6% (1.3%-9.9%)	1.00 (Ref.)	

Metal abutments with external connection	1035	0.17 (0.08-0.38)	0.9% (0.4%-1.9%)	0.24 (0.07-0.86)	p=0.028
Ceramic abutments with internal connection	245	0.27 (0.10-0.69)	1.3% (0.5%-3.4%)	0.37 (0.10-1.40)	p=0.144
Ceramic abutments with external connection	118	0.84 (0.30-2.39)	4.1% (1.5%-11.3%)	1.16 (0.33-4.11)	p=0.817

Table 21. – Summary of annual complication rates, relative complication rates and estimates for bone loss more than 2mm for implants supporting SCs with metal abutments with internal connection as reference.

*   Based on robust Poisson regression.

** Based on multivariable robust Poisson regression.